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USARIEM TECHNICAL REPORT

PHYSIOLOGICAL RESPONSES TO SIMULATED APPROACH MARCH IN DESERT AND TROPIC CONDITIONS: EFFECTS OF THREE MICROCLIMATE COOLING CONFIGURATIONS

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U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and the USAMRMC Regulation 70-25 on the use of volunteers in research.

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ACKNOWLEDGMENTS

The authors acknowledge the members of the Thermal and Mountain Medicine Division for their daily assistance in the successful completion of this study, and Brad Laprise, Walter Teal, and Gary Proulx of the U.S. Army Natick Research, Development and Engineering Center for their technical expertise in both conducting the study and analyzing data for development of this manuscript.

LIST OF ABBREVIATIONS

ACU – Army Combat Uniform

EOD – Explosive Ordnance Disposal

HI – High Cooling

HR – Heart Rate

INT – Intermittent Cooling

LO – Low Cooling

MCCS – Microclimate Cooling System

NC – No Cooling

NSRDEC – Natick Soldier, Research, Development, and Engineering Center

PSI – Physiological Strain Index

RPE – Ratings of Perceived Exertion

RH – Relative Humidity

T_c – Body Core Temperature

TC – Thermal Comfort

T_{db} – Ambient Dry Bulb Temperature

T_{dp} – Ambient Dew Point Temperature

TS – Thermal Sensation

T_{sk} – Mean Weighted Skin Temperature

USARIEM – U.S. Army Research Institute of Environmental Medicine

WBGT – Wet Bulb Globe Temperature

EXECUTIVE SUMMARY

This study supported the U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) effort to develop lightweight microclimate cooling systems (MCCS) for use by dismounted Soldiers by evaluating the cooling potentials of two prototype MCCS. This development is underway because it is known that military operations in warm and hot environments that require wearing helmets and body armor in addition to carrying the added weight of mission essential equipment pose a thermoregulatory challenge to Soldiers. For dismounted troops, load carriage of the cooling system imposes an additional metabolic burden and spatial configuration challenge. While HAZMAT and explosive ordnance disposal troops currently have MCCS available to them, it may be possible to extend the application for more dismounted troops by using a smaller capacity MCCS that reduces load carriage, or by using a vehicle-mounted MCCS only during rest periods.

This study evaluated two liquid vapor compression systems in which the components differed in size, weight, and cooling capacity. One system (LO) was 93 cubic inches, and weighed 4.2 kg, with a cooling capacity of 120 W. The other system (HI) was 200 cubic inches, and weighed 6.5 kg with a cooling capacity of 250 W. The nominal 120 W of cooling and 250 W of cooling were each used continuously to reduce heat strain in volunteers exercising in desert (45°C T_{db}, 20% rh) and tropic (35°C T_{db}, 70% rh) environments while dressed and equipped for an approach march with approximately 33kg of clothing and equipment. A third experimental test (INT) was conducted using 250 W of cooling delivered intermittently only during rest periods. On this test, no cooling was delivered during exercise; however, the cooling vest was worn. A control test (NC) was also performed in each environment with no cooling provided at any time. On this test the volunteer wore neither the cooling vest nor the MCCS.

The results indicate that HI performed significantly better than either LO or INT, despite the greater load carriage required by the larger, heavier system. The

most significant indications of this are the lower skin temperature in both environments and its impact on reducing core temperature with the potential for an increase in walk time. While LO and INT cooling reduced measures of heat strain relative to NC cooling, HI cooling showed the greatest benefit to lower heat strain and the greatest potential for extended exercise performance. It should be noted that the improvement with INT depends on regular rest intervals and the ratio of rest time to work time. If the mission allows for sufficient rest breaks during which cooling can be applied, then it is possible to reduce the Soldier's heat strain without having access to untethered cooling systems and without the impediment of adding the MCCS to their load-bearing equipment.

INTRODUCTION

Wearing body armor impedes air circulation to the torso and increases insulation, both of which reduce the body's ability to lose heat. Previous data indicate that body armor increases the effective wet bulb, globe temperature (WBGT) index by ~2.8°C (5°F) compared to wearing only the ACU (3,4,14). For Warfighters wearing body armor and operating in warm and hot environments, substantial increases in physiological strain can occur, resulting in performance decrements and reduced tolerance time.

Microclimate cooling systems (MCCS) have proven to be an effective way to reduce heat strain in some specific military applications (5,8,9). These applications are primarily for mounted troops who are tethered to a vehicle-mounted cooling source. For dismounted troops, load carriage of the cooling system imposes an additional metabolic burden and spatial configuration challenge. So far, the only cooling provided for dismounted troops has been for HAZMAT or explosive ordnance disposal (EOD) troops, where the added weight of an MCCS is far outweighed by the benefit of receiving cooling inside the impermeable HAZMAT uniform and the heavily insulated protective equipment worn by EOD troops. It may be possible to extend the application for more dismounted troops by using a smaller capacity MCCS that reduces load carriage, or by using a vehicle-mounted MCCS only during rest periods.

This study supported the U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) effort to develop lightweight MCCS for use by dismounted Soldiers by evaluating the cooling potentials of two prototype MCCS. While the same cooling vest was used with each system, the liquid vapor compression components differed in size, weight, and cooling capacity. One system (LO) was 93 cubic inches, and weighed 4.2 kg, with a cooling capacity of 120 W. The other system (HI) was 200 cubic inches, and weighed 6.5 kg with a cooling capacity of 250 W. The nominal 120 W of cooling and 250 W of cooling were each used continuously to reduce heat strain in volunteers exercising in desert (45°C T_{db}, 20% rh) and tropic (35°C T_{db}, 70% rh) environments while dressed and equipped for an approach march with approximately 33kg of clothing and equipment. A third experimental test (INT) was conducted using 250 W of cooling delivered intermittently only during rest periods. On this test, no cooling was delivered during exercise; however, the cooling vest was worn. A control test (NC) was also performed in each environment with no cooling provided at any time. On this test the volunteer wore neither the cooling vest nor the MCCS.

Purpose

- To compare the relative effectiveness of a 120 W (4.2 kg) MCCS (LO) and a 250 W (6.5 kg) MCCS (HI) used continuously to reduce heat strain in volunteers exercising in simulated desert (45°C T_{db}, 20% rh) and tropic (35°C T_{db}, 70% rh) environments while equipped (including helmet and body armor) for an approach march (basic load without MCCS~33 kg).
- To evaluate the effectiveness of a 250 W MCCS used only during three, 10-minute rest periods (INT) to reduce heat strain in volunteers exercising in simulated desert (45°C T_{db}, 20% rh) and tropic (35°C T_{db}, 70% rh) environments while equipped (including helmet and body armor) for an approach march (basic load ~33kg plus 1.0 kg cooling vest)).

Hypotheses

- Continuous cooling provided by either MCCS will be sufficient to reduce heat strain and increase performance time relative to NC despite the increased load carriage imposed by carrying the ~4.2 kg and ~6.5 kg mock-ups representing the 120 W and 250 W MCCS, respectively.

- Continuous cooling with the 250 W MCCS will be more effective than the 120 W system for reducing heat strain and improving performance, even with increased load carriage imposed by the 250 W mock-up.
- Intermittent cooling provided by 250 W of microclimate cooling only during the 10-min rest breaks will be insufficient to reduce overall heat strain relative to NC. Total performance time will be no different from NC.

Objectives

Results from this study will describe the relative benefits provided by the three MCCS configurations as part of an effort to define the best trade-off between reduced heat strain and additional load carriage (i.e. size and weight of the MCCS) This information will be important for the design and manufacture of an acceptable MCCS for the dismounted Soldier.

METHODS

Experimental Design, Procedures, and Measurements

Subjects

Eight Soldiers (5 male; 3 female) participated in this study. Before testing began all volunteers were fully briefed both orally and in writing on the purpose and risks of the study and gave their written consent to participate in the research. A medical officer cleared the volunteers for participation after a physical examination and medical history review.

Preliminary Tests

The volunteers' age, height, and weight were recorded. Percent body fat was estimated from skinfolds taken at four sites (6). On a familiarization day, the volunteers were introduced to the perceptual measurements to be taken during testing. These included rating their perception of effort (RPE) based on the standard Borg scale (2), rating their thermal sensation (TS) based on a routinely used scale modified from Gagge (7,13), and rating of thermal comfort (TC) on a standard scale derived from Berglund (1).

Volunteers completed a heat acclimation program prior to experimental testing to standardize their physiological state and to reduce the risk of exhaustion from heat strain during the experimental trials. Heat acclimation consisted of 10-12 days of exercise in a 45°C (113°F), 20% rh (31.3°C (88.3°F) WBGT) environment while wearing the Army Improved Physical Fitness Uniform. Core (rectal) temperature and heart rate were measured throughout all heat stress exposures. Treadmill speed was set at 3.5 mph and 4% grade. Volunteers walked continuously until one of three criteria was met: 1) 100 minute walk completed; 2) rectal temperature reached 39.5°C (103.1°F); or 3) volitional exhaustion. Volunteers drank 250 ml (9 oz) of water approximately 1 hour prior to beginning each heat acclimation session. Pre- and post-exercise weights were recorded daily. Each day at the end of heat acclimation, the volunteers drank sufficient liquid to return within 1% of their first morning weight to assure that they did not undergo a progressive dehydration. During each session, the volunteers practiced the three perceptual tests (RPE, TS, and TC) that they would take throughout the course of the experimental trials.

Cooling Tests

Design: There were 8 heat stress tests, with four clothing and equipment configurations used in two environments as shown in Table 1. The two environments were a simulated desert environment (45.0°C dry bulb (T_{db}), 16.9°C dew point (T_{dp}) (20% rh), 1.3 m·sec^{-1} wind speed) and a simulated tropic environment (35.0°C T_{db}, 28.6° T_{dp}, (70% rh), 1.3 m·sec^{-1} wind speed).

Each experimental trial consisted of an initial 10 minute rest period followed by two 50 minute walks on a level treadmill at 4 km·h^{-1} (2.5 mph), with each walk followed by 10 minutes of rest. After the third rest period, subjects completed an exercise bout at ~1000 W by running at 8.05 km·h^{-1} (5.0 mph), 0% grade until they reached either volitional exhaustion or a maximum core temperature of 39.5°C.

Table 1. Simplified test matrix for 4 tests repeated in 2 environments

NC – No cooling. Exercise while wearing ~33 kg of clothes and equipment.	LO - Exercise while wearing ~33 kg of clothes and equipment plus cooling vest and a mock-up of 120W cooling system.
HI - Exercise while wearing ~33 kg of clothes and equipment plus cooling vest and a mock-up of 250W cooling system.	INT - Exercise while wearing ~33 kg of clothes and equipment plus cooling vest. 250W cooling provided at rest. No mock-up carried.

Clothing and Equipment. Each day, volunteers wore baseline clothing consisting of underwear, t-shirt, ACU, socks, boots or sneakers, body armor, helmet and load bearing equipment weighing a total of approximately 33 kg depending on helmet and armor size. During LO tests, they also wore a microclimate cooling vests, as well as a mock-up of the 120 W cooling system. During HI tests, they wore a microclimate cooling vest and a mock-up of the 250 W cooling system. During INT tests they wore a microclimate cooling vest. Garments were laundered daily. Mock-ups were used to represent the size and weight of each prototype cooling system while cooling was provided by a large commercial water chiller and pumps. This allowed measurement of water temperature flowing into and out from each vest so that cooling power could be calculated. Flow rate and water temperature provided by the systems was based on the results of copper manikin testing that estimated these requirements for the torso surface area covered by the microclimate cooling vest.

Methods. In all experiments, heart rate was monitored continuously and recorded every 5 minutes using Polar™ heart rate monitors. All body temperatures were recorded at 1-min intervals. Core temperatures (T_c) were measured using either a flexible rectal thermistor (Physiotemp Instruments) inserted 10 cm beyond the anal sphincter or (n = 1) a VitalSense telemetry pill inserted as a suppository. Mean skin temperatures (T_{sk}) were measured by thermocouple from five sites (forearm, chest, back, thigh and calf) and calculated using the equation: $0.15\ (T_{chest}) + 0.15\ (T_{back}) + 0.3\ (T_{forearm}) + 0.2\ (T_{thigh} + T_{calf})$ (11). Volunteers ate a light breakfast approximately two hours before testing, drank 250 ml of water 1 hour before starting exercise, and drank an additional 300 ml (10.5 oz) of water every 20 minutes during exercise. The volunteers also drank sufficiently at the end of each exercise-heat exposure to return to within 1% of their baseline weight before being released for the day. This assured that they did not progressively dehydrate over the course of testing. Metabolic rate was determined from a 90 second sample of expired air collected after ~25 min of exercise using indirect calorimetry via Douglas Bags, dry gas meter, and TrueMax© metabolic cart. Pre- to post nude weights with corrections for water intake and any urine output were used to calculate total sweat loss in each test. The Physiological Strain Index (PSI) was calculated during the garment tests to assess the relative level of physiological strain among the configurations (10). The PSI is calculated using changes in T_c and HR values and was calculated by assuming an initial resting HR of 72 $b{\cdot}min^{-1}$ (10). RPE, TS and TC assessments were conducted once during rest and every 25 min during each walk.

Statistical Analysis

Core temperature, skin temperature, heart rate and PSI were all analyzed across time, comparing values at 0, 10, 35, 60, 70, 95, 120 and 130 minutes of heat exposure. This allowed for comparisons at the midpoint (35 and 95 min) and end (60 and 120 min) of each exercise bout as well as at the end of each rest period (10, 70 and 130 min). One-way (trial) and two-way (time x trial) analyses of variance for repeated measures were performed. A significant *F*-test was further analyzed with Student-Newman-Keuls *post hoc* test to detect differences among means. Sample size estimates were made *a priori* using $\alpha=0.05$ and $\beta=0.20$ values and assuming a standard deviation of 0.3°C for T_c (3). Power analysis revealed that 5 subjects were sufficient to detect a 1.25-fold (0.375°C) difference for T_c between groups. Statistical significance was set at $p<0.05$. All data are presented as mean ± SD.

RESULTS

The age, height, weight, body fat, and body surface area of the volunteers were: 23.1 ± 3.8 years, 178 ± 23 cm, 66.8 ± 11.3 kg, 20.4 ± 5.9%, and 1.83 ± 0.3 m^2 respectively. Weight of equipment worn and carried for each cooling condition was significantly different (p <0.01) among all configurations in both environments. HI (37.9±0.6 kg) was greater than LO (37.0±0.6 kg) which was greater than INT (33.8±0.6kg) which was greater than NC (32.9±0.6 kg). The relative percentage of nude body weight represented by the clothing and equipment were all also significantly different from each other with HI at 57.8±8.2%, LO at 56.3±8.0%, INT at 51.7±7.4%, and NC at 50.0±7.0%.

45°C, 20% rh Environment

Only 5 volunteers (3 male, 2 female) completed the entire 130 minutes exposure on all four trials in the 45°C, 20% rh environment.

Mean metabolic rates during exercise did not differ significantly among trials with an overall value of 382±46 watts. The time of the 5 mph runs completed at the end of the third rest period did not differ significantly among configurations with HI at 6.2±6.6 min, LO at 4.2±2.6 min, INT at 5.2±4.2 min and NC at 4.4±4.5 min. There were significant differences among the mean cooling rates provided during the four trials. The mean cooling provided during the three 10 minute rest breaks in the INT trial (280±42 W) was significantly greater (p<0.05) than cooling in both the HI (184±26 W) and LO (103±10 W) trials and cooling in HI was significantly greater than cooling in LO (p<0.05). However, when cooling is presented as watt hours of cooling, which takes into consideration the duration that cooling is provided during the 130 minute experiments then cooling in the HI trial (399±57 W·hrs) was significantly greater ($p<0.05$) than cooling in both the LO (223±21 W·hrs) and INT (145±24 W·hrs) trials and cooling in LO was greater than cooling in INT. This takes into consideration the short time that cooling is provided during the INT trials.

Figure 1 shows T_{sk} over time for each cooling configuration during the desert condition. During the HC test, T_{sk} remained below 34°C for the duration of the exposure. At the end of each rest break (min 10, 70, 130); T_{sk} was greater with NC than with any of the three cooling configurations. During the four exercise measurements both LO and HI cooling effectively lowered T_{sk} significantly ($p<0.05$) compared to NC and INT. T_{sk} with HI was significantly lower than with all other configurations during both exercise and rest starting at 35 minutes. This lower skin temperature creates a greater core to skin temperature gradient than in the other conditions resulting in a greater heat transfer away from the core potentially reducing the rise in core temperature as well as lowering HR during exercise heat stress.

By 60 minutes, T_c was greater during NC than with HI or LO and by 95 minutes T_c was greater with NC than INT as well. Additionally, T_c with INT was higher than with HI beginning at 70 min, and T_c with LO was higher than with HI beginning at 120 min. (Figure 2).T_c increased on all trials with exercise, but by 60 min was showing separation among trials. T_c plateaued with HI, increased the most with NC, and was intermediate with LO and INT, with T_c on all trials significantly different from each other at 130 min. The HI plateau after 60 min suggests this level of MCC might allow a longer work duration than the other systems.

Because work in the heat is limited by elevation in T_c, the rate of change in T_c during each minute over the total duration of each test was used to predict time to reach T_c of 39.5°C from a baseline of 37.0°C. Based on the rates of core temperature change, the calculated time to reach 39.5°C in the HI trial was 810±752 min, which was significantly greater than in all the other three trials

($p<0.05$). There were no significant differences among the other three trials with NC 173±38 min, LO 300±92 min, and INT 240±152 min.

HR increased under all test conditions, even within the first 10 min rest period due to heat exposure alone (Figure 3). The increase in HR was larger during NC than during the cooling configurations. During INT, HR was higher than HI only during the last 10 min of exposure.

The calculated PSI reflects the increases in T_c and HR (Figure 4). From 60 minutes on the increase in PSI with all cooling systems was less than with NC. During HI, PSI was lower than INT during the last 30 minutes of exposure, and PSI during HI was also lower than LO during the last 10-15 minutes of exposure.

Sweating rate in the HI trial (12.9±3.4 $g \cdot min^{-1}$) was significantly less than in all of the other trials. There were no significant differences in sweating rate among the LO (16.9±4.3 $g \cdot min^{-1}$), INT (17.8±4.5 $g \cdot min^{-1}$), and NC (18.6±4.1 $g \cdot min^{-1}$) trials.

From 10 minutes on TS with NC was greater than with HI. TS with NC ranged from a low of 5.3 ("warm") at 10 minutes to a high of 6.9 ("very hot") at 120 minutes. With HI the TS ranged from a low of 3.7 ("comfortable") at 10 minutes to a high of 5.1 ("warm") at 120 minutes. Additionally at 120 minutes TS with HI was significantly less than all other configurations which had ratings equating to hot or very hot.

While there were no configuration by time interactions in ratings of thermal comfort, the overall TC with NC of 1.7 ("uncomfortable") was significantly greater than the overall TC with any of the cooling levels, LO at 1.2, HI at 0.8 and INT at 1.1 (all "slightly uncomfortable"). There were no significant differences in RPE among configurations at any time.

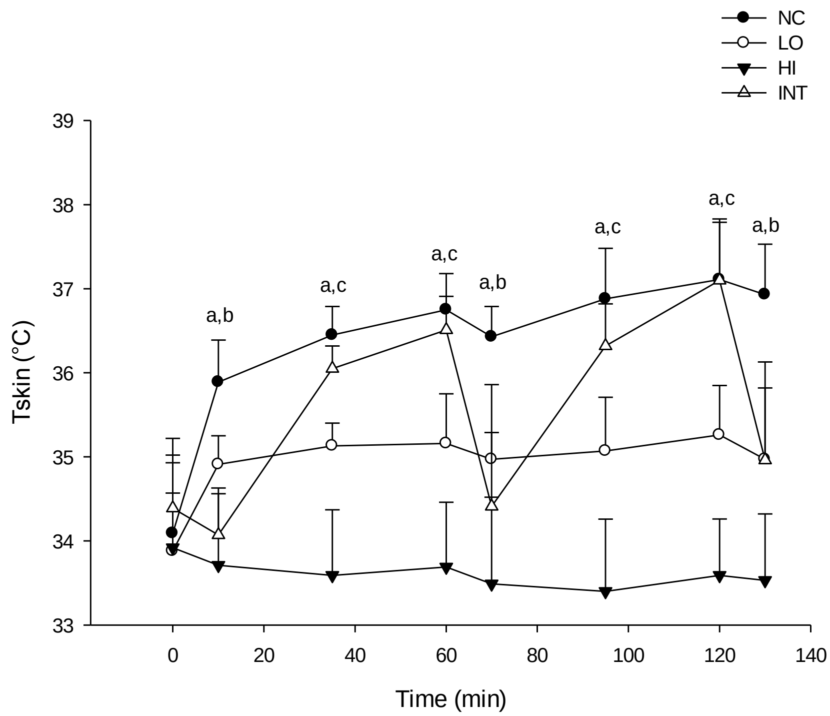

Figure 1. Skin temperature at rest (0,10,70,130) and during exercise in the 45°C, 20% rh environment. a) HI less than all ($p<0.05$); b) HI, LO, INT less than NC ($p<0.05$); c) LO less than NC and INT ($p<0.05$).

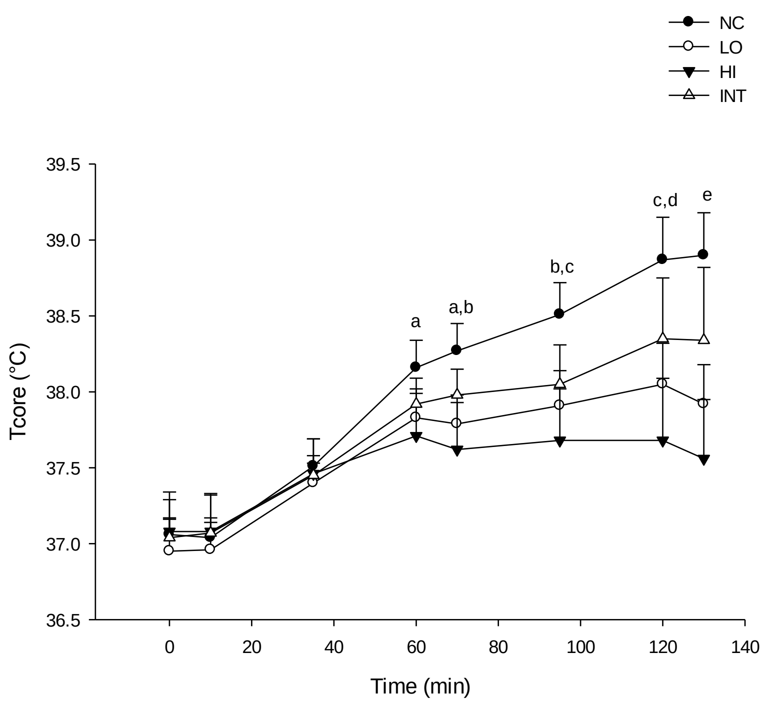

Figure 2. Core temperature at rest (0,10,70,130) and during exercise in the 45°C, 20% rh environment. a) HI, LO less than NC ($p<0.05$); b) HI less than INT ($p<0.05$); c) HI, LO, INT less than NC ($p<0.05$); d) HI Less than all ($p<0.05$); e) All significantly different from each other ($p<0.05$).

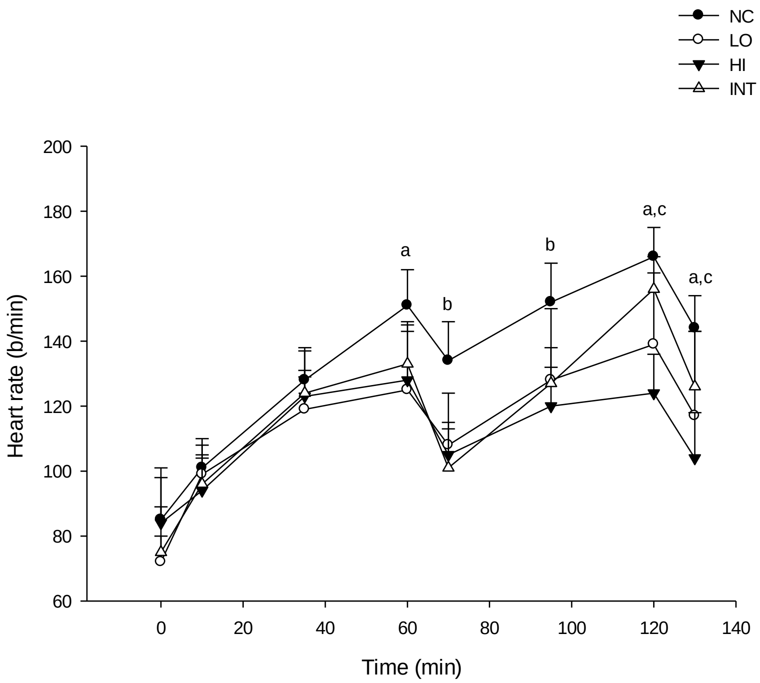

Figure 3. Heart rate at rest (0,10,70,130) and during exercise in the 45°C, 20% rh environment.
a) HI, LO less than NC ($p<0.05$); b) HI, LO, INT less than NC ($p<0.05$); c) HI less than INT ($p<0.05$).

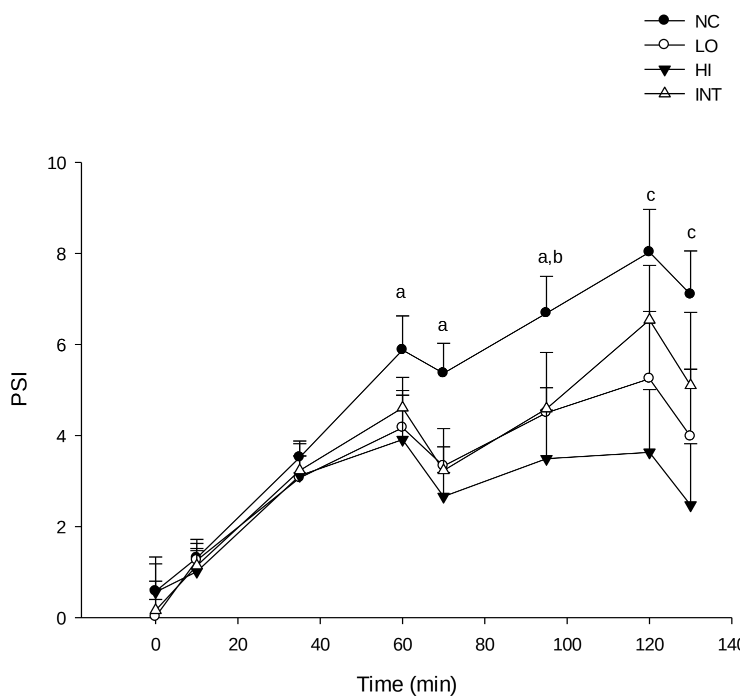

Figure 4. PSI at rest (0,10,70,130) and during exercise in the 45°C, 20% rh environment. a) HI, LO, INT less than NC ($p<0.05$); b) HI less than INT ($p<0.05$); c) All significantly different from each other ($p<0.05$).

35°C, 70% rh Environment

All 8 volunteers completed the experiment in the 35°C, 70% rh environment.

Mean metabolic rates during exercise did not differ significantly among trials with an overall value of 345±57 watts. The time of the 5 mph runs completed at the end of the third rest period did not differ significantly among configurations with HI at 4.3±1.8 min, LO at 4.6±4.4 min, INT at 4.8±2.2 min and NC at 4.1±2.9 min. There were significant differences among the mean cooling rates provided during the four trials. The mean cooling provided during the three 10 minute rest breaks in the INT trial (277±36 W) was significantly greater ($p<0.05$) than cooling in both the HI (151±27 W) and LO (97±17 W) trials and cooling in HI was significantly greater than cooling in LO ($p<0.05$). However, when cooling is presented as watt hours of cooling, which takes into consideration the duration that cooling is provided during the 130 minute experiments then cooling in the HI trial (328±597 W·hrs) was significantly greater ($p<0.05$) than cooling in both the LO (211±38 W·hrs) and INT (138±18 W·hrs) trials and cooling in LO was greater than cooling in INT. This takes into consideration the short time that cooling is provided during the INT trials.

Figure 5 shows T_{sk} over time for each cooling configuration in the tropic condition. During the HI test, T_{sk} fell below baseline values for the duration of the exposure and was significantly less ($p<0.05$) than all other configurations from 10 minutes on. During the LO test T_{sk} did not change significantly with heat exposure remaining close to the baseline temperature of ~34°C throughout. During NC, Tsk increased to ~35.5°C and plateaued, and during INT, T_{sk} fell during rest breaks when cooling was on, but during exercise it rose to nearly the same level as NC.

T_c rose similarly during all four conditions for the first 60 min exposure (Figure 6). During the second walk, T_c rose faster during NC than during the other conditions. The difference in T_c between HI and LO or INT was not significant, except between HI and LO at 120 min.

Because work in the heat is limited by elevation in Tc, the rate of change in Tc during each over the total duration of each test was used to predict time to reach

Tc of 39.5°C. Based on the rates of core temperature change, the calculated time to reach 39.5°C in the HI trial was 670±485 min, which was significantly greater than in all the other three trials ($p<0.05$). There were no significant differences among the other three trials with NC 251±50 min, LO 428±256 min, and INT 351±85 min.

There were no differences in HR among cooling configurations during the first 60 minutes (Figure 7). At 70 minutes, at the end of the second rest, HR recovered more with HI and INT than with NC. From 95 minutes on, HR was higher with NC than with all three cooling configurations.

The calculated PSI was similar among configurations until the end of the first walk, when PSI was higher during NC than HI (Figure 8). PSI was higher during NC than all cooling conditions during the second half of the test. At the end of the second walk (120 minutes) PSI with HI was significantly lower than all other configurations.

Sweating rate in the HI trial (9.0±2.0 $g \cdot min^{-1}$) was significantly less ($p<0.05$) than in both the NC trial (13.7±4.8 $g \cdot min^{-1}$) and the INT trial (12.0±3.3 $g \cdot min^{-1}$). Sweating rate in the LO trial (11.4±3.2 $g \cdot min^{-1}$) was not significantly different from any of the other trials.

In this environment, RPE with NC and INT (14.4, "hard") were greater than with HI (12.8, "somewhat hard") cooling at the end of the first walk. RPE with NC remained greater than with HI throughout the second half of the test, and was also higher than INT at 120 min.

There were no differences in TS among configurations at any time. Subjects felt "comfortable" during the first rest period, climbed to "very warm" by the end of each exercise period, dropping back to "slightly warm" during the rest periods following each walk.

From 35 minutes on, TC with HI was significantly less than with NC during both exercise and rest. During exercise periods with HI cooling TC reached “slightly uncomfortable,” while it reached “uncomfortable” during both exercise periods with NO. Additionally, measurements made during the second exercise at 95 and 120 minutes showed TC with LO cooling also rated at “slightly uncomfortable” and also significantly lower than the “uncomfortable” rating with NC.

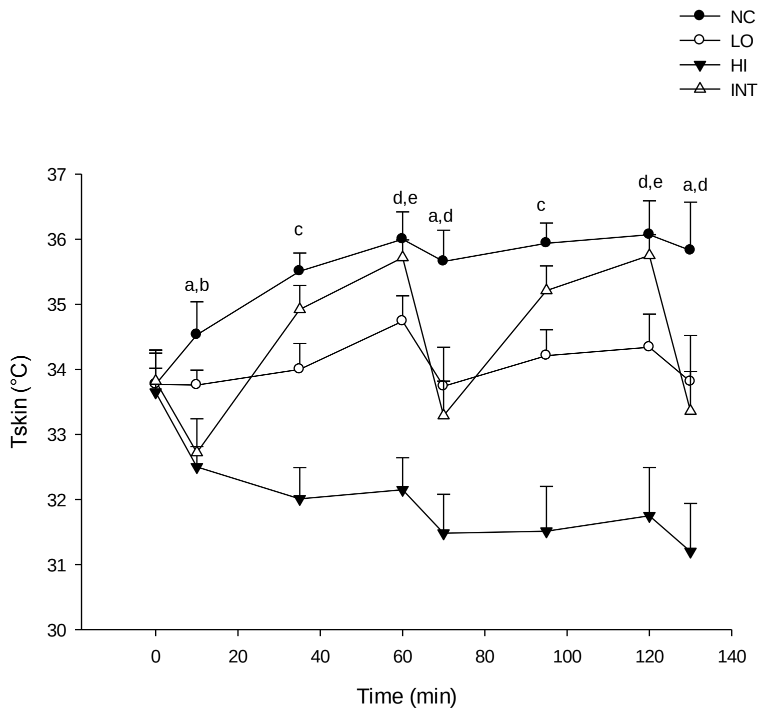

Figure 5. Skin temperature at rest (0,10,70,130) and during exercise in the 35°C, 70% rh environment. a) HI, LO, INT less than NC (p<0.05); b) HI, INT less than LO (p<0.05); c) All significantly different from each other (p<0.05): d) HI less than all others (p<0.05); e) LO less than INT (p<0.05).

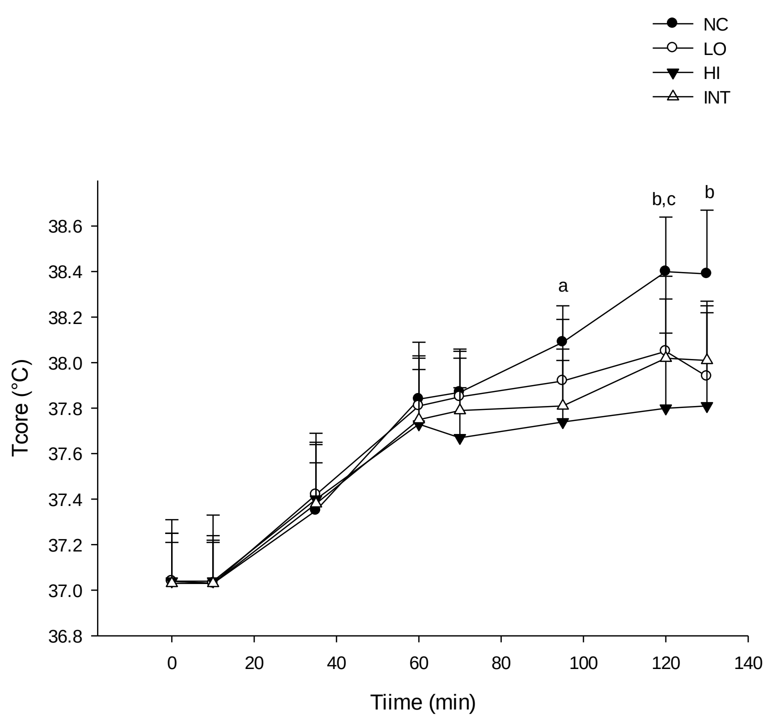

Figure 6. Core temperature at rest (0,10,70,130) and during exercise in the 35°C, 70% rh environment. a) HI, INT less than NC (p<0.05); b) HI, LO, INT less than NC (p<0.05); c) HI less than LO (p<0.05).

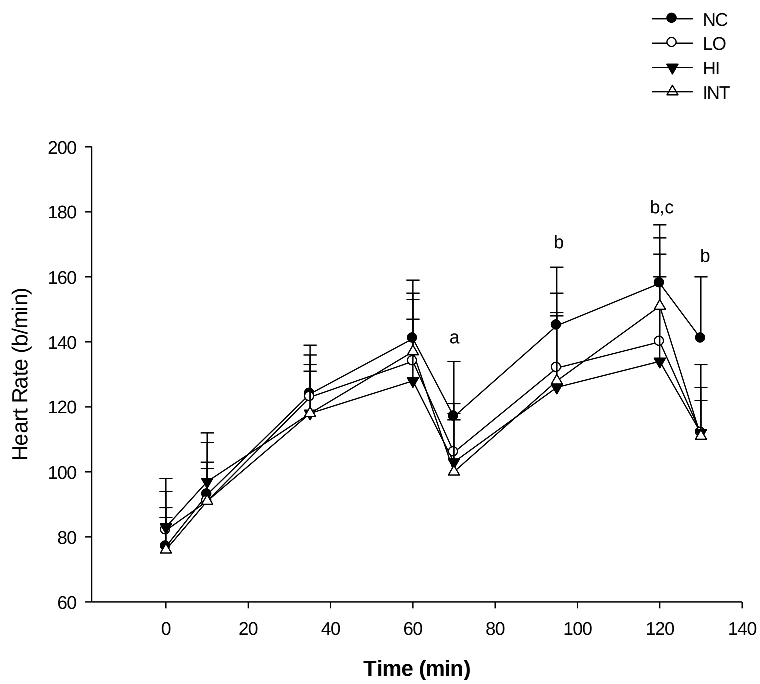

Figure 7. Heart rate at rest (0,10,70,130) and during exercise in the 35°C, 70% rh environment.
a) HI, INT less than NC ($p<0.05$); b) HI, LO, INT less than NC ($p<0.05$); c) HI less than INT ($p<0.05$).

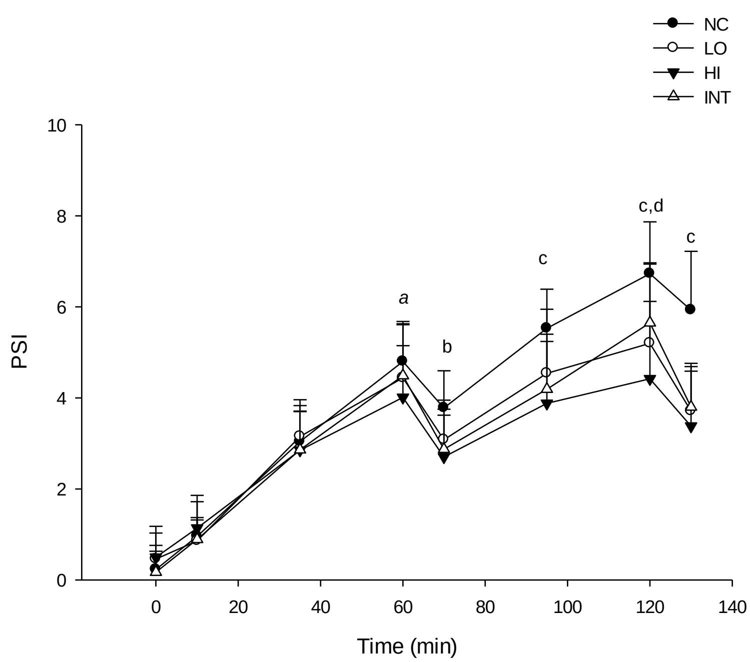

Figure 8. PSI at rest (0,10,70,130) and during exercise in the 35°C, 70% rh environment.
a) HI less than NC ($p<0.05$); b) HI, INT less than NC ($p<0.05$); c) HI, LO, INT less than NC ($p<0.05$); d) HI less than all ($p<0.05$).

SUMMARY

This study evaluated the relative effectiveness of two MCC systems (120 W and 250 W) used continuously and the 250 W system used intermittently - during three, 10-minute rest breaks - on physiological strain while volunteers exercised in two different environmental conditions. The results indicate that the 250 W system performed significantly better than either 120 W or 250 W intermittent, despite the greater load carriage required by the larger, heavier system. The most significant indications of this are the lower skin temperature in both environments and its impact on reducing core temperature with the potential for an increase in walk time (12). When using the changes in core temperature to calculate the time it would take to raise temperature from 37.0°C to 39.5°C, the time with HI cooling was significantly longer in both desert and tropic conditions than all other configurations. However, despite the advantages of the cooling systems for reducing heat strain, this did not translate into better performance on an endurance run after the simulated approach march. The combination of the heavy load being carried and the running speed of 5 mph likely proved more overwhelming than any advantage provided by reduced heat strain.

While LO and INT cooling reduced measures of heat strain relative to NC cooling, HI cooling showed the greatest benefit to lowered heat strain and the greatest potential for extended exercise performance. It should be noted that the improvement with INT depends on regular rest intervals and the ratio of rest time to work time. If the mission allows for sufficient rest breaks during which cooling can be applied, then it is possible to reduce the Soldier's heat strain without having access to untethered cooling systems and without the impediment of adding the MCCS to their load-bearing equipment.

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